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PREDICTING THE RESPONSE OF BIRD POPULATIONS TO WIND ENERGY-RELATED DEATHS

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Abstract

The expansion of wind energy developments has been accompanied by concerns over unforeseen bird deaths caused by striking turbine blades and turbine support structures. We conducted sensitivity analyses using Leslie matrix models to determine the effects of survival of age classes on population growth rates (termed lambda). Population growth rate for ducks is roughly equally sensitive to changes in the juvenile and adult survival rates. For geese, the nonadult age classes survival rates seem to have little impact on population growth. For the adult age class, population growth is extremely sensitive to changes in the adult survival rate. For gulls, except for very small survival rates, the changes in the adult age class gives the largest change in population growth. The situation for the eagle is very similar to the situation for the gull but even more extreme. Our results show that careful evaluation of how life-history parameters could interact to influence population persistence can be used as a first approximation of the influence of wind energy developments on bird populations.

Introduction

The expansion of wind energy developments has witnessed a concomitant increase in concerns over unforeseen negative environmental impacts. This concern has focused primarily on bird deaths caused by striking turbine blades and turbine support structures. Causing the most concern are deaths among birds of prey (raptors). Because many raptor populations are small in size, even a few deaths can cause declines in population size. Further, raptors are protected by various state and federal laws, which raises regulatory barriers to wind-energy developments. Concern has also been raised regarding potential negative impacts to other groups of birds, including waterfowl and migrating songbirds. The National Renewable Energy Laboratory (NREL) has embarked on a multifaceted research program that seeks to determine the level of impact to bird populations associated with wind-energy developments, and further, to develop means of reducing negative impacts when discovered. Although methods are available for making empirically-based estimations of potential impacts, they usually require intensive sampling over a number of years for each species of concern; the cost of such studies can be prohibitive. Given these difficulties, it would be desirable to develop a protocol that could provide at least a preliminary indication of potential responses of birds and bird populations to wind developments.

One of the methods that has high potential for estimating the impacts of a technology on birds is to develop a model of that population over time. Such a model would include parameters that would represent the impact of that technology on the birds. Then, by changing parameter values, a first-order (i.e., initial) approximation of the impact of the technology would be obtained. This approach parallels what is done to gain insight on plagues or medical advances in human populations.

Thus, the goal of our project is to develop a useful, practical modeling framework that can be generalized to most bird species for evaluation of potential wind-farm impacts. We accomplish this by (1) reviewing the major factors that can influence the persistence of a wild population; (2) briefly reviewing various models that can aid in estimating population status and trend, including methods of evaluating model structure and performance; (3) reviewing survivorship and population projections; and (4) developing a framework for using models to evaluate the potential impacts of wind development on birds.

Life History Parameters

Life history parameters are used in the development of population-projection models. For example, combining various ranges of parameters (e.g., clutch size, survivorship, breeding age) can yield substantially different rates of population change. Such analyses provide guidance on whether the population can be sustained under varying expressions of life history traits. Once such relationships are understood, researchers have the opportunity to monitor selected life history traits as part of an assessment of the status of a population. For example, if previous work shows that the timing of breeding is correlated with reproductive output, and thus with population size for the year, monitoring time of breeding can provide an early warning of potential population-level problems.

Adult survivorship is usually very high, especially in long-lived species (such as raptors). Therefore, estimating adult survivorship can tell one a lot about population status.[1] In addition, in most monogamous species, it is female survivorship that is most important to population persistence.[2] At a minimum, then, quantifying adult survivorship provides a preliminary, basic indication of the status of the population. Given any age-specific survival rate, and assuming a stable age distribution, we can estimate the average productivity that must exist in order that the population remains at a constant size.

Modeling Rationale

A central part of impact assessment is development of a model that estimates the survival rates required to maintain a constant population. The strategy is to determine survival rates required to sustain populations exhibiting various combinations of the other parameters governing population size. To be useful in a wide range of environmental situations and useable for people with varying expertise, the model should be based on simple mathematics.

The use of models (of all types) has soared in the past 10 years. In fact, modeling is now a focus of much interest, research, and management action in wildlife and conservation biology. But as in all aspects of science, models have certain assumptions and limitations that must be understood before results of the models can be properly used. Modeling per se is neither "good" nor "bad"; it is the use of model outputs that determines the value of the modeling approach. Modeling requires that all terms be defined precisely. The process of thinking rigorously about the modeling framework is often the most useful product of a modeling exercise.

Leslie Matrix Models

Leslie matrix and similar stage-structured models can give great insight into the processes of population growth.[3] For example, the sensitivity of the population growth rate, r, to perturbations in vital rates for a Leslie-type model can be solved analytically (although potentially severe limitations exist; see beyond). Understanding how growth rate changes in response to perturbations at various stages in a life table may help direct management strategies. For example, adult survival tends to be a parameter to which a model is extremely sensitive in long-lived species, whereas fecundity can be more important in short-lived species.

Matrix models subsume classical life table analysis as a special case but have capabilities that go far beyond that analysis. The theory of these models and detailed descriptions of their formulation and application of matrix models to avian demographic studies have been presented elsewhere.[3,4,5]

The numbers in the body of the matrix are transition probabilities for survival and progression into other stages, while the numbers on the top row of the matrix represent stage-specific fecundity values.[6] A Leslie matrix can be built from estimates of fecundity and survival probabilities, and population growth may be projected for any number of time periods by pre-multiplying the age distribution at each time period by the Leslie matrix to get the new age distribution for the next time period. Thus, we term this matrix the population projection matrix, or the Leslie matrix after its developer.[7]

Population projections using Leslie matrices are a useful approach to the analysis of demography.[8] They provide a numerical tool for determining growth rate and age structure of populations. They are also useful for illustrating and studying the transient properties of populations as they converge to the stable state.

Stage-based matrices (e.g., Lefkovitch models), analogous to the age-based Leslie, can be used to analyze population growth for species in which it is difficult to age individuals, or where it is more appropriate to classify them into life stages or size classes rather than by age; these models are generally referred to as Lefkovitch stage-based models.[9] It is difficult to determine the specific age of most birds and mammals after they reach adulthood. In the case of raptors--the focus of concern in many wind developments--young and subadults can usually be aged up until the adulthood (through differences in plumage and soft tissues, and sometimes eye color). Further, adult raptors can often be placed into categories based on breeding status.

Model Development: Examples for Wind-development Applications

Methods

We reviewed major wildlife and ornithological journals (Journal of Wildlife Management, Condor, Auk, Journal of Raptor Research) published during the past 20 years to determine if any commonality existed among species with regards to annual survivorship; these data are detailed elsewhere.[10] Most data in the articles examined were based on either short-term (usually 1-3 years) telemetry studies, or long-term analyses of band returns. Most of the band return data were obtained from waterfowl harvested by hunters.
In summary, only very broad generalizations can be drawn regarding "normal" survival rates of avian populations. Further, yearly variability in survivorship is large even in healthy populations, which makes short-term (1-2 years) evaluations of a population suspect. Our literature review indicated that yearly survivorship in adult waterfowl was often 60-70%; 80% in gulls; often >75% in raptors; but seldom more than 50-70% in passerines.[10]

To aid in providing general guidelines concerning the potential impacts of wind developments on bird populations, we conducted sensitivity analyses to determine the effects of survival of age classes on population growth rates. We gathered data from the literature on passerines, ducks, geese, gulls, and eagles.[10] These analyses provide a first approximation of how populations of these types of birds respond to hypothetical changes in fecundity and survivorship. They can be used to help focus attention on species most likely to be adversely affected by changes in fecundity and survivorship.

These analyses use a Leslie matrix model.[3] This model breaks the life cycle into stage or age classes and places the survival and fecundity rates for each class into a square projection matrix. This matrix can be multiplied by a vector containing current population sizes for each class to obtain the population sizes for the next year, i.e.

$$n(t+1) = A * n(t),$$

and thus projects population size into the future. This process may be repeated in order to make future predictions or to study the growth rate.

For example, a three age class model would have a projection (or Leslie) matrix:

$$A = \begin{bmatrix} F_1 & F_2 & F_3 \\ P_1 & 0 & 0 \\ 0 & P_2 & P_3 \end{bmatrix}$$

where F_i = fecundity of the ith age class (typically fledglings have $F_1 = 0$) and P_i = the survival rate for the ith class, which may be multiplied by the vector of population sizes time t,

$$n(t) = \begin{bmatrix} n_{t,1} \\ n_{t,2} \\ n_{t,3} \end{bmatrix},$$

where $n_{t,i}$ is the size of the ith age class at time t.

Under certain regularity conditions on the matrix A the population projections converge to a stable age distribution.[3] The largest eigenvalue of the matrix A (eigenvalues solve an equation of the form *A - λI* = 0), is the population growth rate, lambda (λ). If lambda = 1, the population size is remaining constant, if lambda >1 then the population is increasing, and lambda <1 indicates a declining population size.

In the analyses, two age-classes were used for passerines and ducks, three age-classes for geese, seven for gulls, and eight for eagles. The number of classes used was based on the availability of survival and fecundity data by age class in the literature. Because of differences in plumage and morphology among age classes, some groups of birds can be readily divided into a greater number of age classes than other groups. For passerines, ducks, and geese models having `reasonable' survival and fecundity parameters yielding lambda = 1 were constructed. Values for fecundity and survival for age-classes of eagles and gulls were modified from results presented elsewhere.[11,12] These values resulted in lambda slightly larger than one (1.07 for eagles and 1.046 for gulls).

Passerine - Two Age Class Model $\lambda = 1$
F1 = 0, F2 = 3, P1 = 0.2 and P2 = 0.4.

Duck - Two Age Class Model $\lambda = 1$
F1 = 0, F2 = 1.33, P1 = 0.3 and P2 = 0.6.

Goose - Three Age Class Model $\lambda = 1$
F1 = 0, F2 = 0, F3 = 0.476, P1 = 0.3, P2 = 0.7 and P3 = 0.9.

Gull - Seven Age Class Model $\lambda = 1.046$
F1 = 0, F2 = 0, F3 = 0, F4 = 0.0174, F5 = 0.43878, F6 = 0.66172, F7 = 0.71, P1 = 0.607, P2 = 0.8, P3 = 0.853, P4 = 0.853, P5 = 0.853, P6 = 0.853 and P7 = 0.853.

Eagle - Eight Age Class Model $\lambda = 1.07$
F1 = F2 = F3 = F4 = F5 = F6 = F7 = 0, F8 = 0.74, P1 = 0.71, P2 = 0.95, P3 = 0.95, P4 = 0.95, P5 = 0.88, P6 = 0.88, P7 = 0.88 and P8 = 0.88.

With the models in place, each survival rate parameter was allowed to vary from zero to one while the remaining parameters were held constant. The new value of lambda was calculated at each new value of the changing parameter. Once these data were obtained for each survival parameter, the results were plotted on a graph so as to see the different effects each parameter had on the population growth rate. This can be viewed as a way of expressing the sensitivity of lambda to the different survival parameters. It is important to distinguish between the true effect on the population (which is unknown), and the effect on lambda, which assumes the model is the "correct" model.

Results

Passerines-The curves for the passerine show that lambda is much more sensitive to changes in the juvenile survival rate than to changes in the adult survival rate (Fig. 1). Also, the juvenile survival rate curve has a very steep slope as the juvenile survival gets very small.

Ducks - The curves for the duck show that lambda is roughly equally sensitive to changes in the juvenile and adult survival rates (Fig.2).

Geese - The nonadult age classes survival rates seem to have little impact on the value of lambda (Fig. 3). For the adult age class lambda is extremely sensitive to changes in the adult survival rate.

Gulls - Except for very small survival rates, the changes in the adult age class gives the largest change in lambda (Fig. 4). The other classes all have very similar curves.

Eagles - The situation for the eagle is very similar to the situation for the gull but even more extreme. There is great sensitivity of lambda to changes in adult survival rate (Fig. 5).

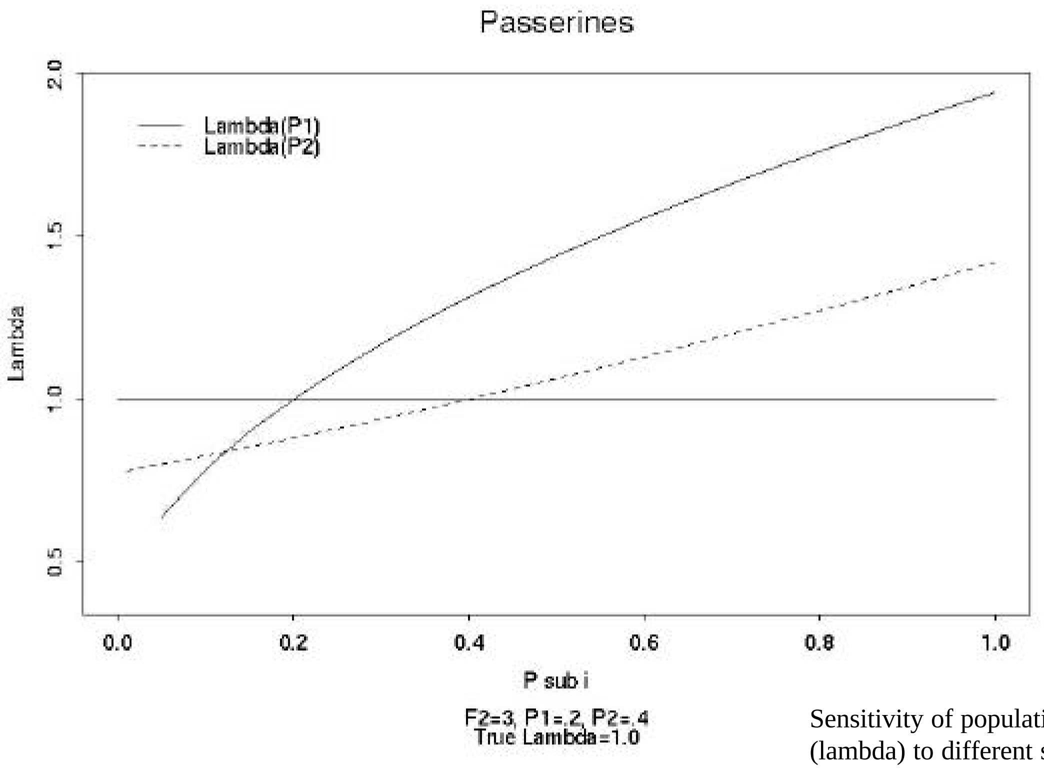

Figure 1

Sensitivity of population growth rate (lambda) to different survival parameters, where F=fecundity of an age class, P=survival rate for an age class. See text for description of methods.

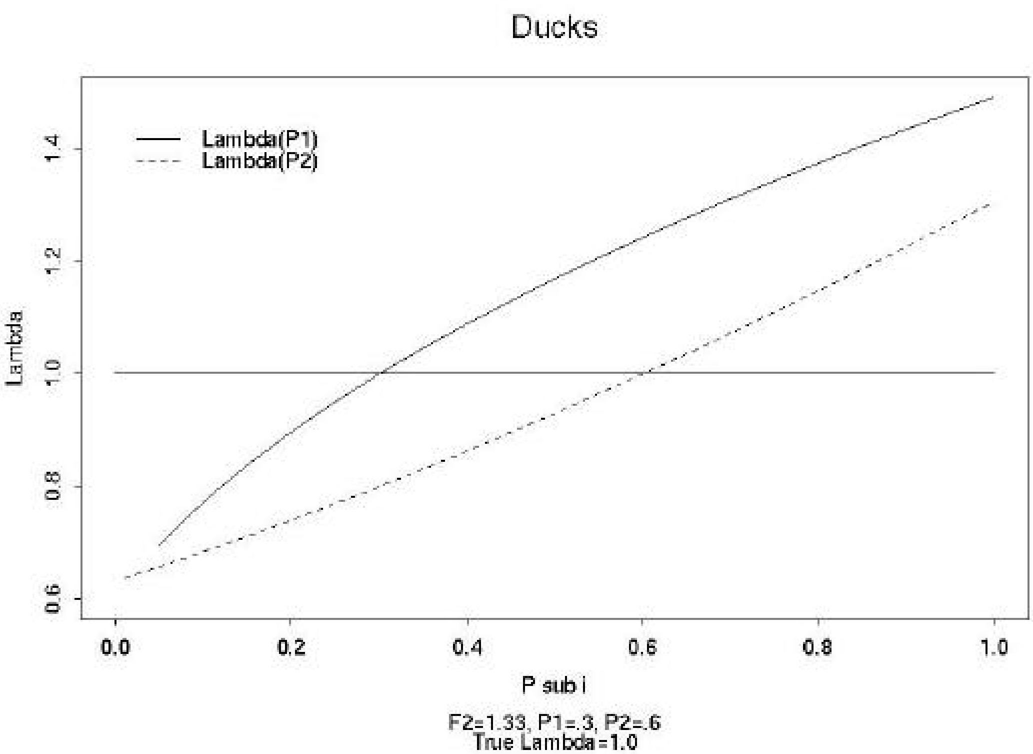

Figure 2

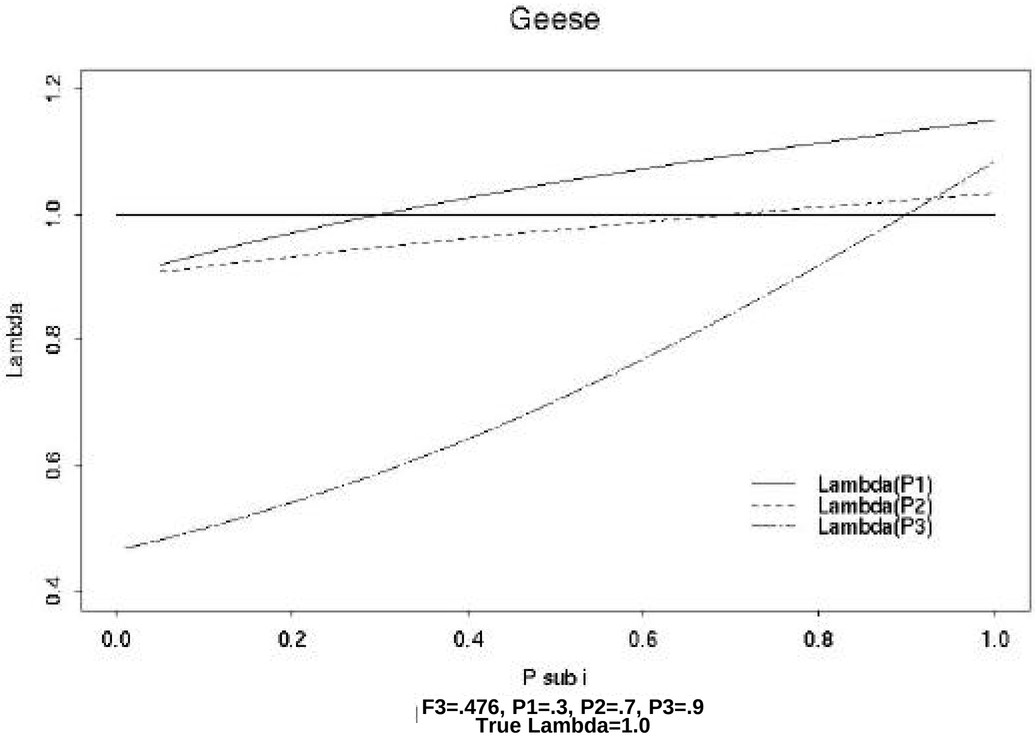

Figure 3

Sensitivity of population growth rate (lambda) to different survival parameters, where F=fecundity of an age class, P=survival rate for an age class. See text for description of methods.

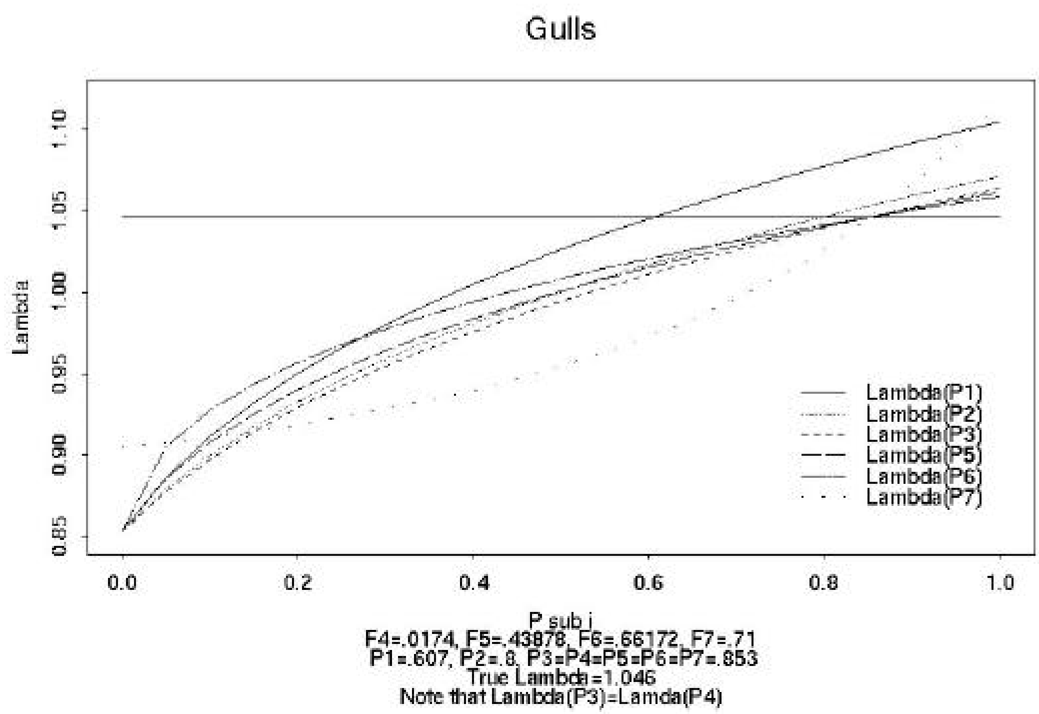

Figure 4

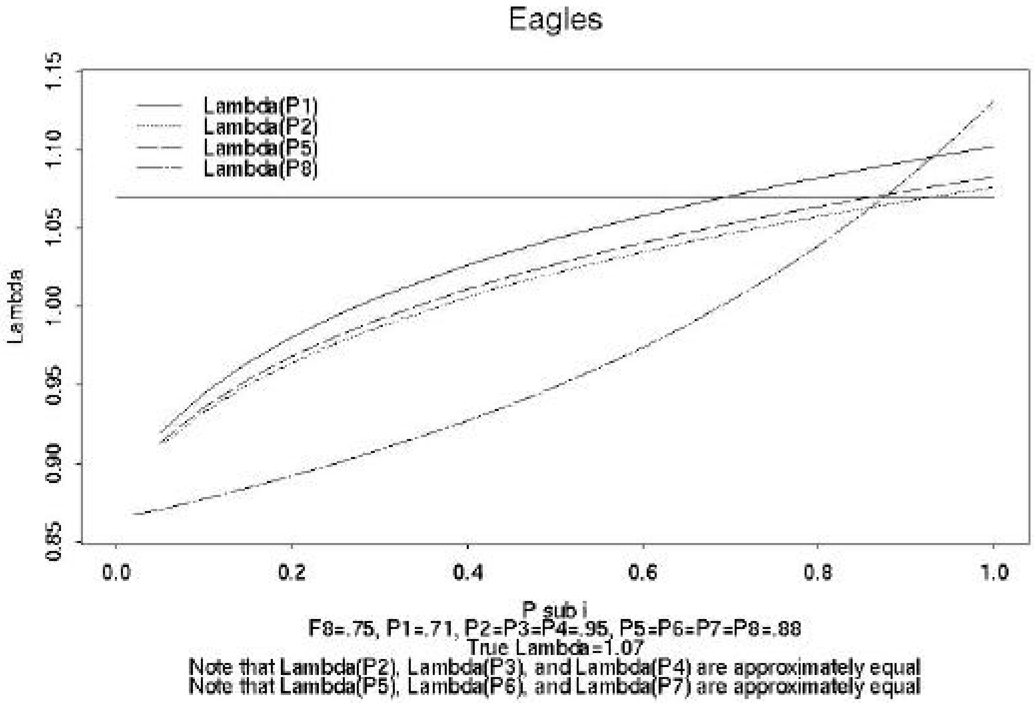

Figure 5

Sensitivity of population growth rate (lambda) to different survival parameters, where F=fecundity of an age class, P=survival rate for an age class. See text for description of methods.

Discussion

Results of these evaluations should be considered approximations of population status and longer-term persistence. It is imperative to continue to study the situation, should the wind development be approved, in order to improve the initial approximation. This would also improve the evaluation process in future impact assessments by providing additional empirical data. The models developed herein assume a stable age distribution. If the population is being impacted then model parameters will likely change over time. Indeed, population parameters are usually changing in response to natural and human-induced environmental changes. Thus, the population projection approach described herein should be used as a simple, yet informative, first approximation of the status of the population of interest. Initial results may then be used to determine if more intensive study is necessary.

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